

Prebiotic Synthesis of Activated Amino Acids

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About four billion years ago chemical processes occurring on the primitive Earth yielded molecules that had the ability to make copies of themselves (i.e., replicate). These rudimentary replicating molecules eventually developed into today's life that uses both protein and DNA molecules for replication. Since the DNA of today's life is too complex to have been chemically made on the primitive Earth, the first replicating systems may have been composed solely of small proteins, called peptides. Peptides are good candidates for the first replicating molecules because they are constructed from very simple building blocks—activated amino acid molecules that could have been made by chemical processes on the primitive Earth.

In order to understand how activated amino acid and peptide molecules could have been generated 4 billion years ago on the primitive Earth, work centered on three principal study areas: (1) The synthesis of activated amino acids was investigated in the laboratory under simulated primitive Earth conditions. (2) The thermodynamics of carbon chemistry was systematically explored to establish the chemical constraints that govern the synthesis of molecules (amino acids, etc.) needed for the operation and origin of life. (3) Techniques were developed to analyze amino acids from extraterrestrial sources, such as Martian meteorites.

In the past year, significant progress has been made in each of the three research areas listed above. A new prebiotic pathway has been discovered that generates activated amino acid thioesters which are capable of forming peptides. This synthetic pathway functions by converting formaldehyde and glycolaldehyde (one- and two-carbon aldehydes) into sugars that subsequently react with ammonia in the presence of thiol catalysts to give alanine and homoserine thioesters. This "one-pot" synthesis of amino acids operates under mild aqueous conditions, and like

modern amino acid biosynthesis, uses sugar intermediates which are converted to amino acids by energy-yielding redox (reduction and oxidation) reactions. Additionally, in order to identify the thermodynamic constraints that govern carbon chemistry related to the origin of life, the free energy was calculated for making and breaking all the possible aliphatic carbon-carbon bonds. This thermodynamic analysis of carbon chemistry revealed that the biosynthetic processes of life are driven by chemical energy made available by redox disproportionation of carbon groups of sugars. It was established that the favorable energy of redox disproportionation was based on the universal reduction potentials of carbon groups. This thermodynamic perspective reveals that the high energy content of sugars makes them the optimal substrate for the synthesis of the molecules needed for life and its origin.

Finally, in preparation for the analysis of Martian meteorite samples, an improved analytical method of detecting amino acids was developed. Together with upgrades in high-performance liquid chromatography (HPLC) instrumentation, the improved method is capable of detecting 1 femtomole (a femtomole is 10^{-15} mole) of amino acid enantiomer. By combining this improved HPLC analytical system with a new electrophoretic method of sample preparation, 26 femtomoles of the meteoritic amino acid, α -aminoisobutyric acid, was detected in 1 gram of Cretaceous-Tertiary boundary sediment. Knowledge of the amino acids in extraterrestrial materials (like Martian meteorites) contributes to understanding the chemistry of amino acid synthesis on the primitive Earth during the origin of life.

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